Feasibility test of 193 nm wavelength inspection for extreme ultraviolet mask

Guk-Jin Kim[1*], In-Seon Kim[1], Soo-Yeon Mo[1], Michael Yeung[2], Eytan Barouch[3], Chang-Moon Lim[4] and Hye-Keun Oh[1†]

[1]Lithography Lab., Applied Physics, Hanyang University, Ansan, Gyeonggi-do, Korea

[2]Fastlitho, San Jose, CA, U.S.A.,

[3]Boston University, Boston, MA, U.S.A.,

[4]SK Hynix Semiconductor Inc., Icheon, Gyeonggi-do, Korea

HANYANG UNIVERSITY

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Introduction

- **The issue of EUV mask inspection**

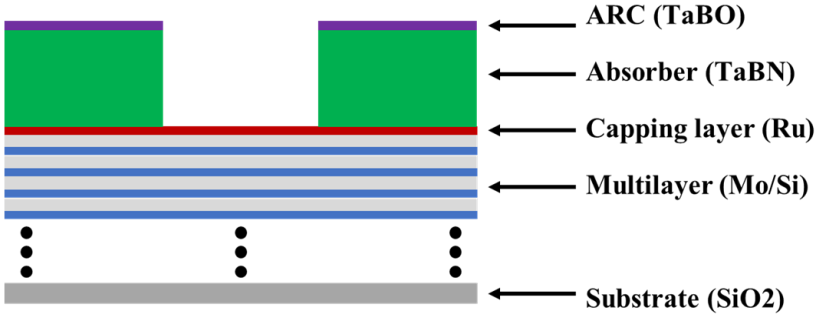
EUV mask	193 nm inspection
❖ Reflective mask ❖ Complicated mask structure (Mo/Si 40 multilayers)	❖ Resolution limit $\left(Resolution = k_1 \frac{\lambda}{NA}\right)$ ❖ Low reflectivity at EUV mask

✓ **We need to improve inspection performance to detect smaller defect of the EUV mask with 193 nm inspection because 13.5 nm actinic inspection is not ready yet.**

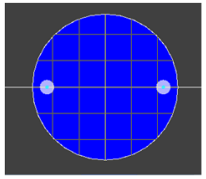
✓ **We should minimize the inspection ability gap between the actinic and 193 nm inspections.**

Simulation Conditions

- **Mask structure (16 nm L/S Pattern)**



- **Inspection conditions**

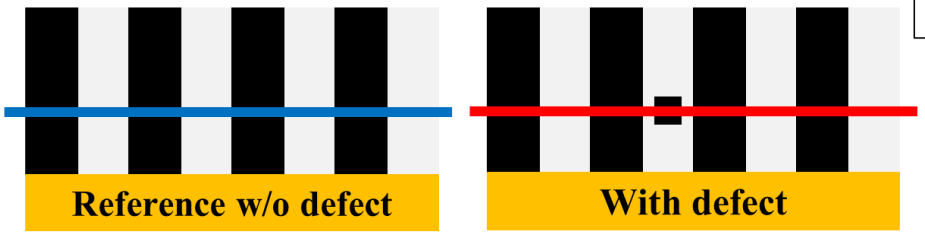
Illumination shape	 <Dipole>
Coherence (σ_r_σ_c)	0.1_0.8
Wavelength (nm)	193
NA	0.88

- **Material information of the EUV mask (at 193 nm wavelength)**

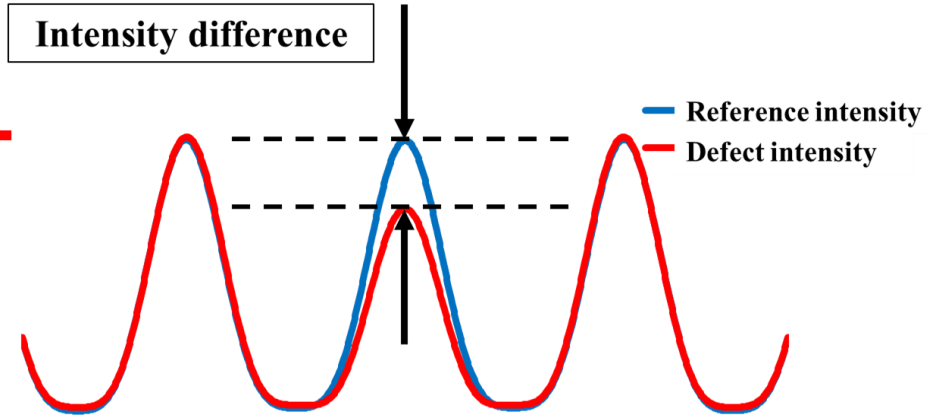
	Material	Thickness (nm)	n	k
Absorber + ARC	TaBO	2	2.490	1.080
	TaBN	50	2.170	2.190
Capping Layer	Ru	2.5	0.824	2.196
Multilayer	Si	4.2	0.974	2.100
	Mo	2.8	0.788	2.346

Simulation Results

- **Absorber defect inspection**



$$Normalized\ Intensity\ Difference = \frac{(Reference\ intensity) - (Defect\ intensity)}{(Reference\ intensity)}$$

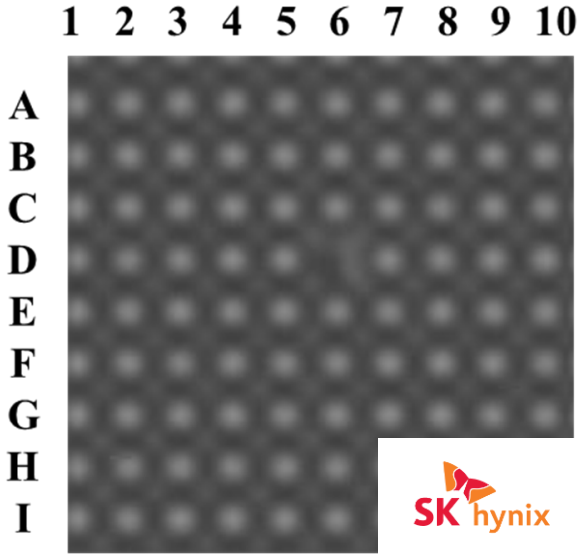


✓ **The normalized intensity difference (NID) is used to check the inspection ability for 193 nm inspection.**

Simulation Results

▪ Absorber defect inspection

- 193 nm inspected image for 30 nm CH



- NID of left image

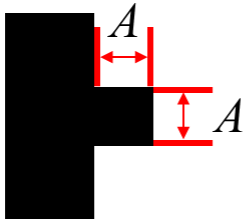
	1	2	3	4	5	6	7	8	9	10
A	0.02	0.02	0.04	0.00	0.04	0.03	0.04	0.00	0.04	0.00
B	0.03	0.02	0.02	0.00	0.04	0.03	0.02	0.00	0.01	0.02
C	0.00	0.02	0.07	0.01	0.04	0.04	0.00	0.06	0.04	0.01
D	0.01	0.02	0.04	0.01	0.00	0.20	0.01	0.01	0.01	0.06
E	0.00	0.02	0.00	0.03	0.01	0.01	0.01	0.00	0.01	0.02
F	0.02	0.01	0.07	0.00	0.01	0.02	0.02	0.04	0.02	0.01
G	0.01	0.01	0.05	0.00	0.00	0.02	0.03	0.03	0.01	0.02
H	0.02	0.00	0.05	0.03	0.02	0.02	0.02	0.02	0.02	0.02
I	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

✓ **Image shows only one clear defect that can be seen with bare eyes. However, there are several smaller defects that cannot be seen with bare eyes, but can be differentiated from the rest with NID.**

Simulation Results

- **Inspection limit of absorber defects by 193 nm**

- **Defect size**



Defect size = A

Extrusion defect | Intrusion defect | Pindot defect | Pinhole defect

Simulation Results

- 193 nm inspection and corresponding NID

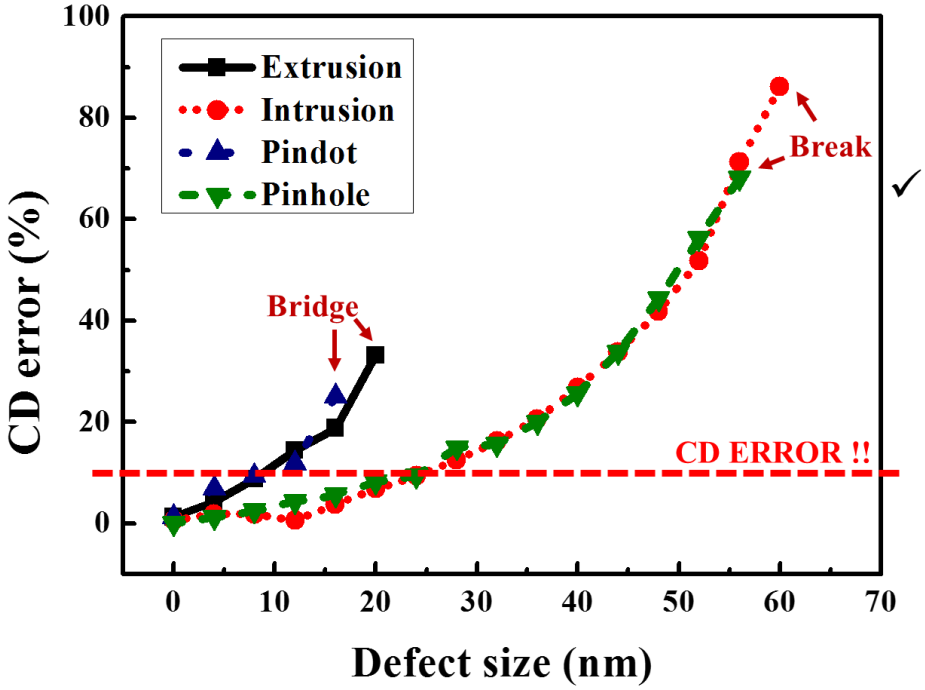
	Extrusion	Intrusion	Pindot	Pinhole
64 nm				
50 nm				
40 nm				
30 nm				
20 nm				
14 nm				
0 nm				

	Extrusion	Intrusion	Pindot	Pinhole
64 nm	0.31	0.24	0.31	0.24
50 nm	0.31	0.18	0.33	0.16
40 nm	0.25	0.14	0.34	0.10
30 nm	0.15	0.10	0.24	0.05
20 nm	0.07	0.06	0.11	0.03
14 nm	0.03	0.03	0.05	0.01
0 nm	0	0	0	0

- ✓ We can digitize 193 nm inspection image and take NID to distinguish the small defects.
- ✓ NID = 0.05 is chosen to be a 193 nm inspection threshold that matches 13.5 nm inspectability.

Simulation Results

- **Absorber defect inspection with 13.5 nm actinic inspection**



$$CD\ error\ (\%) = \frac{\Delta w}{w} \times 100$$

✓ **Defects that can make ±10% CD error is taken as a criterion for 13.5 nm actinic inspection.**

Defect	Pindot	Extrusion	Intrusion	Pinhole
Detectable defect size by 13.5 nm	**10 nm**	**12 nm**	**28 nm**	**28 nm**

✓ In the following figure, red colored lines indicate CD errors more than 10%.

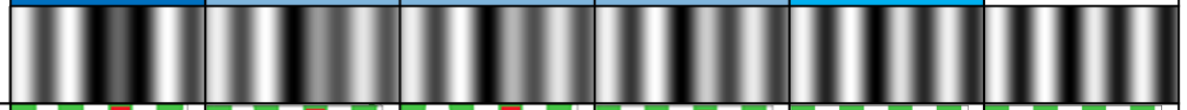
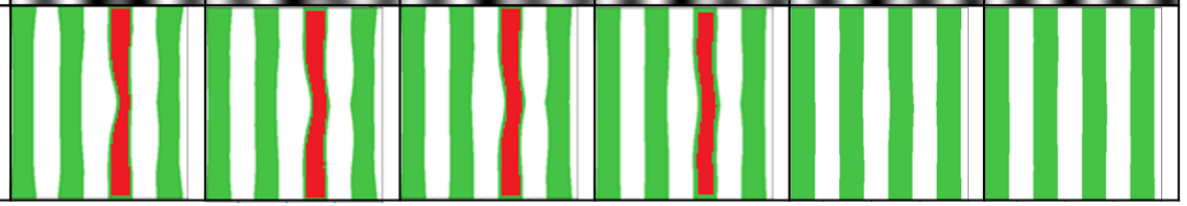
✓ Thus detectable defect sizes above are chosen that do not make such CD errors.

Simulation Results

- **Extrusion**

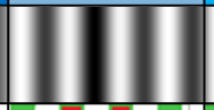
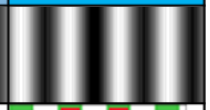
Defect size	64 nm	50 nm	40 nm	30 nm	20 nm	14 nm
193 nm inspection	0.31	0.31	0.25	0.15	0.07	0.03
						
13.5 nm inspection						

- **Intrusion**

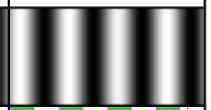
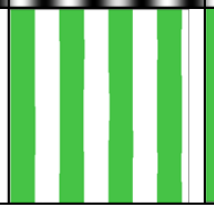
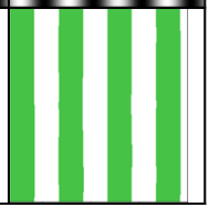
Defect size	64 nm	50 nm	40 nm	30 nm	20 nm	14 nm
193 nm inspection	0.24	0.18	0.14	0.10	0.06	0.03
						
13.5 nm inspection						

Simulation Results

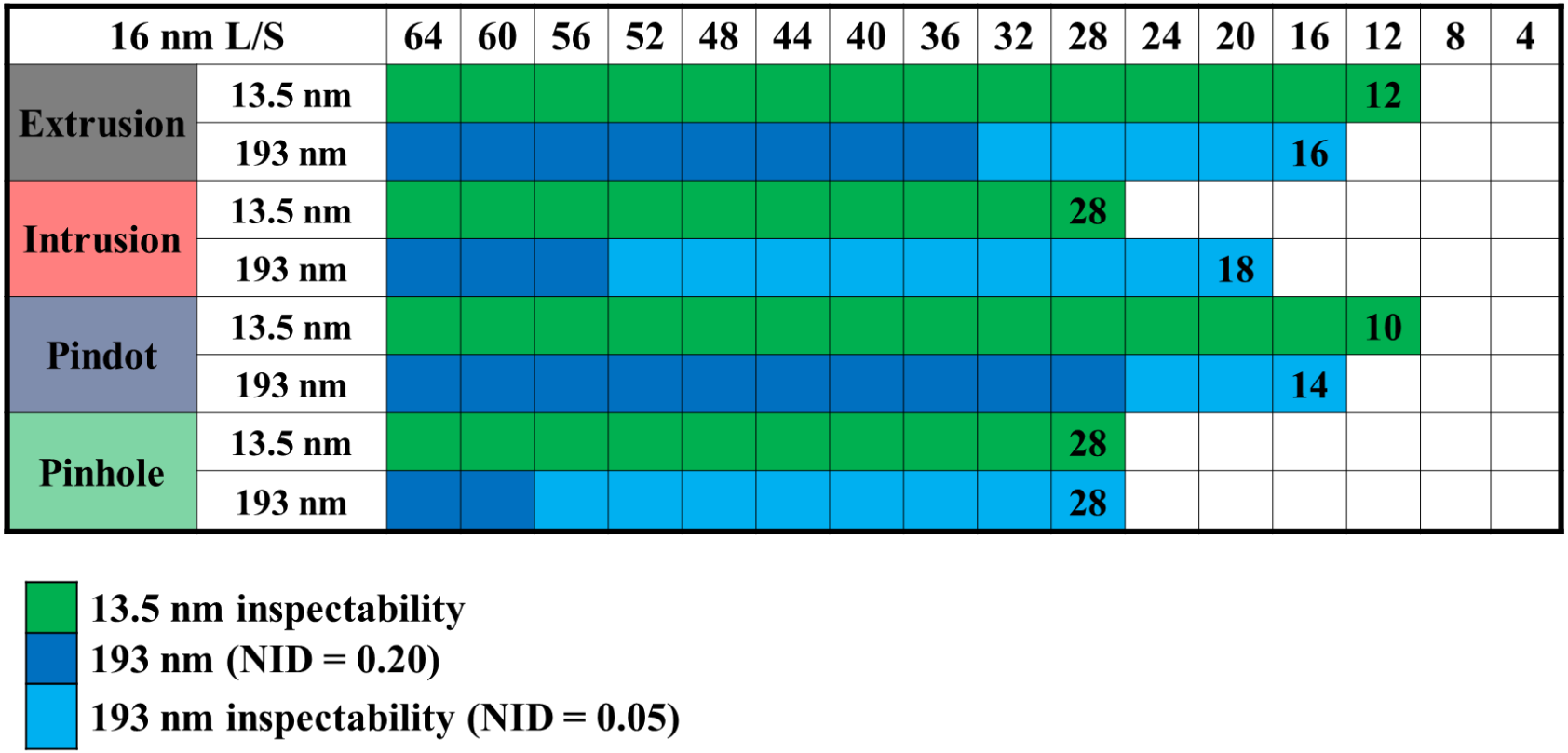
- **Pindot**

Defect size	64 nm	50 nm	40 nm	30 nm	20 nm	14 nm
193 nm inspection	0.31	0.33	0.34	0.24	0.11	0.05
						
13.5 nm inspection						

- **Pinhole**

Defect size	64 nm	50 nm	40 nm	30 nm	20 nm	14 nm
193 nm inspection	0.24	0.16	0.10	0.05	0.03	0.01
						
13.5 nm inspection						

Conclusion


16 nm L/S
64
60
56
52
48
44
40
36
32
28
24
20
16
12
8
4
Extrusion
13.5 nm
193 nm
Intrusion
13.5 nm
193 nm
Pindot
13.5 nm
193 nm
Pinhole
13.5 nm
193 nm
12
16
28
18
10
14
28
28
13.5 nm inspectability
193 nm (NID = 0.20)
193 nm inspectability (NID = 0.05)

Conclusion

- ✓ **We used the digitized image to evaluate the limit of 193 nm inspection.**
- ✓ **The detectable defect size depends on normalized intensity difference threshold.**
- ✓ **We can match the detectable defect size limit of 193 nm inspection to that of actinic 13.5 nm inspection if we choose proper image threshold.**
- ✓ **Minimum detectable defect size is different if the defect type is different.**